Economy and Environment Program
for Southeast Asia
22 Cross Street
#02-55 South Bridge Court
Singapore 048421
Tel: (65) 6438 7877
Fax: (65) 6438 4844
E-mail: eepsea@idrc.org.sg
Website: www.eepsea.org

RESEARCH REPORT

No. 2008-RR2

A Cost-Benefit Analysis Of Alternative Pig Waste Disposal Methods Used In Thailand

Siriporn Kiratikarnkul
Faculty of Economics, Maejo University
64 M.4 Sansai-Praw Rd
Nong-harn Sub-district, San-sai District
Chiangmai, Thailand 50290
Tel: 66 53 873000 ext 80
Email: kiratikrankuls@gmail.com

This study looks at the costs and benefits of the main pig waste disposal options used by intensive pig farmers in Thailand. It aims to see which alternatives give the most benefits to farmers and to society as a whole. It also aims to understand why farmers are reluctant to adopt biogas conversion technology, as this approach is being heavily promoted by the government.

The study finds that, as it is currently implemented, biogas conversion actually provides fewer benefits than many of the other waste management solutions that are being used. However the report also finds that, if the necessary technical and financial support are extended to help farmers use biogas to produce electricity and sell this to the national grid, then biogas conversion would become a good option.

The study, which was conducted by Siriporn Kiratikarnkul from Thailand, recommends that the Thai government should provide technical and financial support to encourage pig farmers to install biogas systems and help them generate electricity and sell it. It highlights the fact that there is a pressing need to support and promote this renewable energy source, which would benefit pig farmers, the environment and the economy in general.

Published by the Economy and Environment Program for Southeast Asia (EEPSEA)
22 Cross Street #02-55, South Bridge Court, Singapore 048421 (www.eepsea.org)
tel: +65-6438 7877, fax: +65-6438 4844, email: eepsea@idrc.org.sg

EEPSEA Research Reports are the outputs of research projects supported by the Economy and Environment Program for Southeast Asia. All have been peer reviewed and edited. In some cases, longer versions may be obtained from the author(s). The key findings of most *EEPSEA Research Reports* are condensed into *EEPSEA Policy Briefs*, available upon request. The Economy and Environment Program for Southeast Asia also publishes *EEPSEA Special Papers*, commissioned works with an emphasis on research methodology.

Library and Archives Canada Cataloguing in Publication

Kiratikarnkul, Siriporn

A Cost-Benefit Analysis of Alternative Pig waste Disposal Methods Used in Thailand / Siriporn Kiratikarnkul

(Research report, ISSN 1608-5434 ; 2008-RR2)
Includes bibliographical references: p.

Co-published by the International Development Research Centre.
ISBN 978-1-55250-081-1

1. Swine--Manure--Thailand--Management.
2. Farm manure--Economic aspects--Thailand.
3. Farm manure--Environmental aspects--Thailand.
4. Biogas industry--Thailand.
I. International Development Research Centre (Canada)
II. Economy and Environment Program for Southeast Asia
III. Title.
IV. Series: Research report (Economy and Environment Program for Southeast Asia); 2008-RR2.

TD930.2.P64K57 2008 636.4’083809593 C2008-980303-5

A Cost-Benefit Analysis of Alternative Pig Waste Disposal Methods Used in Thailand

Siriporn Kiratikarnkul

July, 2008

Comments should be sent to: Associate Professor Siriporn Kiratikarnkul, Faculty of Economics, Maejo University, 64 M.4 Sansai-Praw Rd., Nong-harn Sub-district, San-sai District, Chiang-Mai, Thailand 50290.

Tel: +66053873000#80 Fax: +66053873154

Email: kiratikrankuls@gmail.com

EEPSEA was established in May 1993 to support research and training in environmental and resource economics. Its objective is to enhance local capacity to undertake the economic analysis of environmental problems and policies. It uses a networking approach, involving courses, meetings, technical support, access to literature and opportunities for comparative research. Member countries are Thailand, Malaysia, Indonesia, the Philippines, Vietnam, Cambodia, Lao PDR, China, Papua New Guinea and Sri Lanka.

EEPSEA is supported by the International Development Research Centre (IDRC); the Swedish International Development Cooperation Agency (Sida); and the Canadian International Development Agency (CIDA).

EEPSEA publications are also available online at http://www.eepsea.org.

ACKNOWLEDGEMENTS

I would like to thank Dr. David Glover and Dr. Herminia Francisco for the financial and technical support provided by the Economy and Environment Program for Southeast Asia (EEPSEA). I would also like to express my profound appreciation to Dr. David James not only for his professional advice, knowledge and encouragement, but also his cheerful moral support. Without him, this report would not have been completed. I also wish to thank the farmers who participated in this study and my research assistants for the information, documents and data collected for this research. Finally, the administrative/organizational support from the Department of Livestock Development (DLD), Ministry of Agriculture, is gratefully acknowledged.

Any shortcomings found in this report remain those of the author.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

A COST-BENEFIT ANALYSIS OF ALTERNATIVE PIG WASTE DISPOSAL METHODS USED IN THAILAND

Siriporn Kiratikarnkul

EXECUTIVE SUMMARY

This study carried out a cost-benefit analysis of alternative methods of animal waste disposal used on pig farms in three main livestock regions of Thailand in which intensive pig farming has increased rapidly in recent years.

The results of the study showed that among five existing methods of waste disposal, the Net Present Value (NPV) of the promoted technological method, i.e., converting the pig waste to biogas, was lower than the NPVs of some of the other methods. However, the sensitivity analysis to determine the “best case” and “worst case” scenarios showed that the “best case” (providing the highest benefits) was the conversion of pig waste to biogas with the sale of the surplus electricity generated from the biogas to the Electricity Generating Authority of Thailand (EGAT).

The study recommends for the government to implement policies to promote the production of renewable energy as well as provide the necessary technical and financial support to encourage pig farmers, especially of medium and large-scale farms, to install biogas systems. The surplus gas has potential economic value, but that potential is not being realized. There is a pressing need to create the necessary conditions that would allow this readily available renewable energy source to be fully tapped, thus benefiting both the farmers as well as the economy of Thailand.

1.0 INTRODUCTION

1.1 Pig Production in Thailand

Pig production in Thailand increased by 3.5% per annum between 1992 and 2005, reaching the quantity of approximately nine million pigs each year (Table 1). Pig farming is carried out in all twelve “livestock regions” of the country (see Figure 1), with about 25% of the total produced in Region 7, 21% in Region 2, about 7% in Region 3 and approximately 8% in Region 5. These four regions, in aggregate, account for roughly 61% of the total number of pigs produced (See Table 1). The Central Region of Thailand (especially the part of it in the vicinity of Bangkok) has been the most productive area of the country.

Over a relatively short period of time (less than 30 years), pig farming in these four regions of Thailand has completely changed from small-scale production on mixed farms to large-scale, intensive production. All marketed pigs from intensive pig farms in Thailand are collected by butchers and transported to slaughterhouses in remote locations. Environmental pollution is a much more serious problem in these four regions compared to the rest of Thailand. The problem has been and will continue to be the focus of much attention and concern from the government. In the other eight regions, pig farming remains mostly small-scale, carried out on mixed farms using traditional methods.

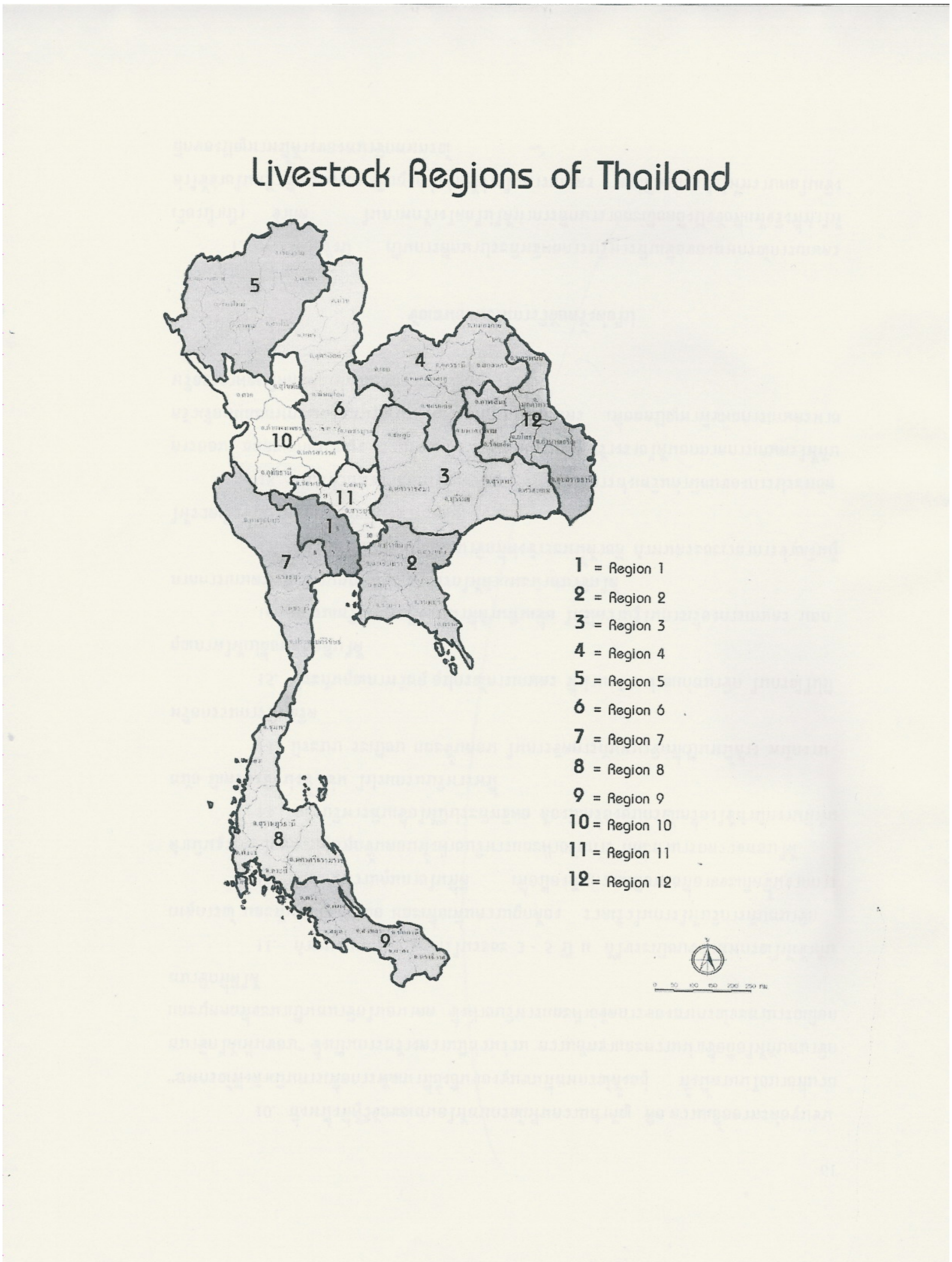

Figure 1. Livestock regions of Thailand

Table 1. Statistics of swine production in Thailand in 1999 and 2005 by livestock region

Livestock areas divided by DLD	Number of pigs (2005)	%	Number of pigs (1999)	%
Region 1	410,916	4.66	336,372	4.30
Region 2	1,853,413	21.00	1,427,632	18.27
Region 3	615,758	6.98	669,655	8.57
Region 4	589,580	6.68	370,470	4.74
Region 5	855,104	8.56	634,731	8.12
Region 6	494,254	5.60	333,075	4.26
Region 7	2,271,948	25.75	2,235,706	28.61
Region 8	329,130	3.73	484,839	6.20
Region 9	254,423	2.88	332,185	4.25
Region 10	540,016	6.12	245,821	3.15
Region 11	429,780	4.87	393,499	5.04
Region 12	279,884	3.17	351,068	4.45
Whole Country	8,924,206	100.00	7,815,053	100.00

Source: The Statistics Branch of the Planning Division, Department of Livestock Development (DLD) (2007)

Modern farms today no longer combine crop production with animal husbandry. Diversified crop production and mixed farming (a combination of crops and small numbers of livestock) have been replaced by mono-cropping. Animal husbandry is now organized as large-scale, specialized “industrial” production of livestock. These changes have resulted in an increase in productivity of both crops and livestock. Assisted by research and development, livestock production efficiency has risen rapidly and the quality of output is also considerably higher than from traditional farming methods. Most of the waste from intensive farming systems (e.g., solid and liquid waste, foul odours and pathogens) have become externalities for the farming sector as well as the rest of society. Among the problems which contribute to ecological imbalances are: severe eutrophication[1] of surface water, leaching of the underground water table, and deposits of heavy metals which create pathogens harmful to humans and animals. These problems are more severe in the case of intensive pig production than for other kinds of intensively-produced livestock.

In the case of intensive pig farms, although many large-scale farms have complied with recent environmental protection regulations, small and medium-sized farms, mostly operating along the banks of rivers, have not done so. It is not probably not possible to enforce all the protective regulations, such as the Environmental Development and Quality Promotion Law (EDQP 1992) and other recent laws related to public health by enforcing the closure of offending farms. The Department of Livestock Development (DLD) of Thailand and the Food and Agriculture Organisation (FAO) have formulated and implemented environmental protection policies and are now searching for efficient technological innovations which could profitably utilize animal waste products, especially the slurry from pig farming.

There are five different options in pig waste management in Thailand. The first is the conversion of the waste into biogas, using either the fixed concrete dome system or the plastic-covered lagoon system. The second is using the waste as fish feed while the third is

[1] Eutrophication is an increase in chemical nutrients in an ecosystem, usually with a resultant increase in the ecosystem's primary productivity, and other effects including lack of oxygen and severe reductions in water quality and fish and other animal populations.

to dry the waste and sell it as organic fertilizer. The fourth method is simply to dump the waste into a deep pond dug out on the farmer's own farm. The last option involves a combination of the biogas, fish feed and organic fertilizer methods.

1.2 Alternative Methods of Pig Waste Disposal

As mentioned above, there are five alternative methods of disposal of pig waste practised in Thailand. Figures 2-5 illustrate the first four methods.

Biogas

The use of biogas technology is intended to provide for the energy needs of the farm itself as well as to avoid the negative environmental impacts that other methods of pig waste disposal normally give rise to. However, this method has had limited success (see 1.3).

Figure 2. Converting the pig waste into biogas by means of a concrete dome digester

Fish feed

Some farmers try to dispose of pig waste by creating large ponds, stocked with catfish, on their farms. Recycling pig waste in this way serves the dual purpose of protecting the environment and producing economic benefits from the sale of the fish. However, this alternative requires a large suitable piece of land to build the fish pond on.

Moreover, the poor quality of the water means that only catfish can be bred. This alternative also requires considerable investment and labour and is generally inadequate in effectively disposing of the huge volume of waste produced by large farms.

Figure 3. Using pig waste as fish feed

Organic fertilizer

Among the five options, the production and sale of organic fertilizer is the simplest method of pig waste management. It also requires little initial investment. In order to produce a saleable commodity, large pits are filled with pig waste which is then dried out. The resulting odour is, however, offensive to those living in the neighbourhood. Moreover, during the rainy season, this technique fails to work effectively and excess waste overflows the pits. It is unsatisfactory because it does not prevent serious pollution of the environment. Recently, the local government has tried to enforce protective regulations such as the Ministerial Notification on Livestock Farm Standards of Thailand (1999) which was launched by the Department of Livestock Development. This law requires the farmers to take measures to control pollution and prevent epidemics. The farm's waste such as garbage, carcasses, manure and waste water must be properly disposed of.

Figure 4. Drying the waste before selling it as organic fertilizer

Deep pond

A small percentage of pig farmers, who have very limited spare land, dump their pig waste into a deep pond on their farms. These farms are always located away from the neighborhood, because the waste (which is left in the pond for years) gives off a very bad smell. Therefore, the local government has to enforce protective regulations on these farmers.

Figure 5. Dumping the waste into a deep pond

1.3 Research Problem

The use of biogas technology has been adopted by Thai farmers since the early 1970’s. The major reasons for biogas adoption were, first, a response to a government policy of making Thailand self-sufficient in energy and, second, an attempt to find an effective solution to environmental problems caused by large-scale livestock production. The main target groups were medium and large-scale pig farms. The Thai government set up the National Energy Policy Office (NEPO) on 16 October 1986 to promote renewable energy production in the country. NEPO spent 5,100 million baht during the period 1990-2000 on a special programme to subsidize Thai pig farmers (NEPO, 2004), but the programme had only limited success because of the problems listed below.

a) High investment cost to the farmers (even though NEPO was willing to subsidize up to 38% of the cost for medium-sized farms and 18% for large-sized farms).

b) Ineffective use of the biogas produced and no incentive to invest the capital necessary to turn the surplus biogas into energy such as electricity.

c) The farmers preferred other waste management alternatives such as producing organic fertilizer and fish feed, which are simpler methods that do not require much initial investment and at the same time, generate cash instead of adding to the cost of pig production.

This programme is now in its third phase of seven years, 2002–2008. (The first phase was from 1991–1995 and the second was from 1996–2000). It is anticipated that at the end of this phase, there will be sufficient biogas systems to process the waste from 2.4 million pigs (with a total biogas digester volume of 200,000 cubic metres). Although NEPO still subsidises part of the installation costs of a new system, many farmers are not yet convinced that converting pig waste into biogas is the best and most economical solution for them. Furthermore, the expectation that any surplus biogas produced beyond domestic requirements could be sold has not been fulfilled. Installed biogas systems can produce 220 volts of electricity, which is suitable for use on the farm, but further investment is required to purchase the very expensive equipment necessary to convert the voltage to the required national standard before it can be sold to EGAT.

The main aim of this study was to determine how well biogas production compares with the other pig waste disposal options, based on assessments from both a socio-economic perspective and a private financial perspective. The biogas option has been available for some time and has indeed been encouraged by the Thai government through capital subsidy grants and concessional rates for loans by farmers who choose to invest in this technology. However, the uptake rates have not been as high as expected as many farmers have been reluctant to adopt the technology to date.

1.4 Research Objectives

The general objective of this study was to carry out a cost-benefit analysis of five alternative methods of pig waste management in Thailand.

The specific objectives of this study are given below.

a) To evaluate the costs and marketable benefits of the five alternative methods of pig waste disposal.

b) To undertake a cost-benefit analysis (CBA) of each alternative pig waste disposal option.

c) To identify the factors influencing farmers' adoption of the biogas option as well as the technical and institutional barriers to each of the alternative methods.

1.5 Research Questions

This study sought to answer the following research questions.

a) How do farmers dispose of pig waste and how much initial investment is required?

b) What actual costs do farmers incur in disposing of pig waste by means of each disposal alternative?

c) What and how much are the benefits from each alternative method of disposal?

d) Among the five disposal options considered, which is the best alternative in terms of net benefit per metric tonne of slurry?

e) What factors, including technical and institutional barriers to each alternative method, influence farmers to install a biogas system?

2.0 PREVIOUS STUDIES ON ANIMAL WASTE MANAGEMENT

This literature review section is divided into three parts. The first part summarises some international studies dealing with the issues of waste, emissions and pollution from pig production. The second part is a review of the environmental impacts of intensive animal farming from a global perspective while the third part describes a few case studies in Asia on pollution control options for livestock waste.

2.1 Waste, Emissions and Pollution from Pig Production

Factory farms cause pollution of the environment because the nutrient input of chemical fertilizers, feed and manure is greater than the nutrient output from the farm (in terms of animal or plant products). Farm animals can only absorb and utilize a small amount of the nutrients they eat and any nitrogen and phosphorus not used by the animal for body growth is excreted in the faeces and urine. Pigs excrete up to 58% of the nitrogen contained in their feed, the protein level of which is too high, resulting in excessive nitrogen excretion. Nitrogen and phosphorus from pig manure can contaminate surface water and can leach through the soil into ground water. Another problem is the creation of ammonia gas from manure or stored slurry. Ammonia gas causes acid rain. Animal farming, particularly dairy and pig farming, in the Netherlands for example, accounted for 94% of the total emissions of ammonia in that country (Berentsen and Giesen 1996).

Intensively-farmed animals produce very large quantities of excreta which is rich in nutrients but potentially polluting to the environment. In the UK, the Ministry of Agriculture, Fisheries and Food estimated in 1990 that manure accounted for a quarter of the total of two million tonnes of nitrogen applied to agricultural land as fertilizer. The total land needed for sustainable disposal of the nitrogen from the UK pig herd is nearly 0.2 million hectares and the sustainable disposal of pig manure needs over 3% of the total arable land of the UK (Atkinson and Watson 1996).

Silverman (1999) estimated that 1.4 billion tonnes of solid manure was produced by US farm animals per year. In addition, the total waste from farm animals was 136 times that produced by the human population and a pig production operation, producing 2.5 million pigs a year, would have a waste output greater than the urban area of Los Angeles. The amounts of waste per animal per year were about 4,000 kg for cattle, 400 kg for sheep and 450 kg for pigs compared to only about 300 kg for a human being (Silverman 1999).

Despite the concern long expressed by environmental experts, there is evidence that some livestock farmers may still be unaware of their industry's potential for environmental damage. A 1994 report by Richert et al (1994), for example, revealed that when Kansas pork producers were surveyed, it was found that less than half of them were concerned about nitrates in swine manure, a potential environmental hazard, and only 27% showed concern about the phosphorus content of swine manure. A study by Wathes et al (1997) on environmental impact assessments submitted by farmers under planning rules for intensive livestock developments found only 10% of them to be adequate compared to other planning applications and only a few farmers used soil or ecological consultants, or showed any understanding of surface and ground water problems.

The smell from factory farms is a major cause of complaint from members of the public. Farm buildings smell because of the decay of organic matter such as faeces, urine, skin, hair, and feed, and sometimes also bedding. The Institute of Grassland and Environmental Research (Pain 1994a) estimated that there were around 4,000 complaints of bad smell from farms every year, mainly emanating from manure spreading, livestock buildings and waste stores. Pig farms headed the list of complaints (57%), followed by poultry farms (27%), cattle farms (17%) and feed processing (10%) (Pain 1994b.)

2.2 A Global Perspective of the Environmental Impact of Intensive Animal Farming

The demand for cereals and meat by the world's human population is predicted by the FAO to rise by at least 50% to 275-360 billion tonnes by the year 2020 (FAO 1995). If this prediction is correct and if intensive animal farming continues to grow, the inevitable result will be more intensive land and water use for animal feed, with equally inevitable environmental degradation. Industrial animal farming already puts natural resources under stress and causes severe localised pollution in many developing countries. The spread of intensive animal farming throughout the world cannot be seen as a sustainable solution and many organizations such as the Compassion in World Farming Trust believes that the FAO should take the lead in rejecting the spread of intensive animal farming and promote animal husbandry methods that are appropriate to local conditions and which respect biodiversity, animal welfare and the environment (CWFT 1996). The Compassion in World Farming Trust also believes that environmentally-friendly farming and higher standards of animal welfare are closely linked. In the UK and Europe, the way forward must be via the encouragement of extensive animal farming and mixed farming together with commitments from governments and the farming industry to make environmental protection and animal welfare priorities. This would result in the end of government subsidies that encourage high stocking densities and over-production, and their replacement with subsidies for environmentally-friendly methods of farming. In the context of world trade, the values of environmental protection and animal welfare must be given appropriate weight beside the values of free trade (Hann, Steinfeld and Blackburn 1996).

Research studies in North Carolina (e.g., USEPA 1995; WSPA 1999) showed that airborne ammonia and nitrogen released from intensive pig farms were at levels higher than those from all other state livestock and industrial sources. Meanwhile, in Minnesota, hydrogen sulphide emitted by decomposing pig waste was found to far exceed the standards (Delgado et al 1999). Anaerobic lagoons which are used as treatment plants for animal waste in the state also produce methane gas as a by-product. Methane is a potent greenhouse gas that contributes to global warming. Sixteen percent of the world's yearly production of methane is accounted for by livestock and manure management (Delgado et al 1999).

2.3 Pollution Control Options for Livestock Waste: A Few Cases in Asia

An economic assessment of pollution control methods used by dairy cattle-raising households in the North Vietnamese district of Gia Lam was made by Nguyen (2004). The study found that the pollution resulting from dairy cattle raising increased with the scale of production, causing negative impacts on the environment and health of both people and animals. Among the available pollution control options, biogas digesters were found to produce the most positive economic and environmental benefits. However, the expansion of the technology faced difficulties. The main methods adopted to further promote the biogas option were choosing the appropriate pollution control technology for each region, providing technical and financial support, encouraging the installation of large-scale biogas digesters at the commune level, and changing the behaviour of local residents i.e., moving them away from traditional waste disposal methods (without pollution control) towards biogas technology.

A study of environmental, health and other negative effects of pig waste in the Philippine province of Majayjay showed that the worst of these adverse environmental effects were surface and ground water contamination, air pollution from odours and greenhouse gas emissions (Catelo, Dorado and Agbisi 2001). The researchers found that the pollution control options for pig waste practised by the farmers in the study area were biogas and organic fertilizer plants. The results of the financial and economic analyses showed that both options were viable and that the commercial biogas system yielded the highest NPV. The use of biogas and pelletised organic fertilizer was shown to generate high economic returns. However, many of the farmers were resistant to proposals to give up traditional practices, such as the production of organic fertilizer, and adopt the new biogas technology which was dependent on there being government subsidies for investment costs. They preferred to make organic fertilizer, which was easily marketable, rather than convert the slurry into biogas. Moreover, although surplus electrical energy produced by biogas-driven generators could be sold to the national electricity boards in developed countries, such is not the case in developing countries. An option recommended by the researchers was subsidizing the investment costs of control options (i.e., the biogas and organic fertilizer plants) through more affordable credit schemes or through the donation or lease of unused, disposable public land on which to build biogas or fertilizer systems.

A study on pig slurries conducted in Vietnam by Pain, Misselbrook and Crarkson (1990) concluded that biogas digestion reduced odour emission by between 70-74%. The average manure DM (decimetre) percentage was 25% and the loading rates ranged from 0.1 to 1.2 kg per DM^3 of digester liquid volume. Biogas digestion decreased Chemical Oxygen Demand (COD) from 35,610 mg/litre in the inlet stage to 13,470 mg/litre in the effluent stage indicating a process efficiency of 62% (COD removal rate). The volume of gas per capita per day required to cook three meals is about 200 litres.

Research by Intarangsi (2002) in Thailand showed that the inefficiency of biogas digesters and the general failure of the technology could be blamed on the design of the digester. The study found that a scum layer of manure and water in the digester prevented gas generation and leakage of the gas was due to the poor quality of the materials used in the construction. In general, knowledge about the biogas generation process using anaerobic micro-organisms was at a low level among pig farmers.

3.0 RESEARCH METHODOLOGY

3.1 Approaches to Evaluating Pig Waste Management Options

In evaluating pig waste management options, there are basically two approaches that can be taken:

a) View the waste as a nuisance that has to be eliminated. This approach focuses on finding the (best) option that minimizes the net cost of getting rid of the waste.

b) View the waste as a resource. This approach focuses on finding the (best) option that maximizes the net benefits.

Whichever approach is adopted, the results (i.e., ranking of options) are the same, as one set of results is only a “mirror image” of the other. A benefit is the same as a negative cost (i.e., a cost offset), and a cost is the same as a negative benefit. The second approach is the one adopted in this study i.e., all the evaluations are conducted in terms of net benefits.

The net benefits of the options in pig waste management are analysed from a **social (cost-benefit analysis-CBA)** perspective, and a **private (financial analysis)** perspective. Cost-benefit analysis is a tool that will help pig farmers make better informed decisions about their resource allocations. By measuring and comparing the costs and consequences of various interventions, relative efficiencies can be assessed and future budget requirements estimated. Efficiency is defined as achieving a specific goal at the highest net benefit. A CBA is undertaken for each alternative and the net present values (NPVs) are estimated. The alternative that has the highest net benefit is the most efficient and preferred. There are some important differences between the economic and financial analyses of the options. These are discussed below in the context of the present study.

An economic analysis is conducted from the perspective of the community as a whole. It focuses on "real" resource costs and benefits, including any "external" environmental costs and benefits that affect the broader commnity. Loan repayments and/or subsidies are not part of the economic analysis. Only real resource costs, incurred at the time of their utilisation, count. The farmers are members of the community and the costs and benefits they face will necessarily be a major component of the social costs and benefits of the whole community. But farmers do not incur the costs and benefits of externalities of pig waste disposal. Their welfare depends mainly on their after-tax financial returns. This means that their welfare has to be assessed using financial evaluation techniques. The external costs caused by unpleasant odours and other pollutants associated with the different waste management options are, however, taken into account in an economic analysis. Part of such costs can be measured in terms of property value differentials. Properties affected by offensive odours and pollution will tend to have lower values than those in a non-polluted environment. The differentials in property values (i.e., the extent to which property values are lower because of pollution) provide an estimate of the environmental damage cost.

From a private perspective, similar concepts apply as in the economic analysis, but the benefits and costs are estimated in terms of the financial benefits received and costs borne by private producers. What we need to estimate is the net financial benefit per tonne of pig waste disposed of under each option. The option with the highest net returns is the best from a private financial perspective. Cash costs will consist of investment costs, additional equipment costs, and operating and maintenance (O&M) costs. The way the costs of the initial capital investment are calculated depends on how much is outlaid directly by the farmer, any subsidies that are received, and the interest rate that is charged on borrowed funds. Direct investments by farmers (using their own savings or funds) will be a direct financial capital cost. Any upfront capital subsidy paid by the government will be a financial benefit and hence a cost offset. Where a lower, concessional interest rate is charged, the cost savings (compared with a higher market rate of interest) will also represent a benefit or cost offset in calculations of private financial net benefits. The sales of products that are produced by each waste management option, i.e., fertilizer, fish feed, biogas and electricity, are the financial benefits of each option.

Because a financial analysis is focused only on the farmers' private financial prospects and does not take into account externalities or external environmental costs, it is inadequate in determining the efficiency of resource allocation. Nevertheless, it is the best way to financially assess different options. The main reason for conducting a financial analysis here was to see whether, and if so, how much more subsidies might be required to induce farmers to switch to biogas production rather than continuing to use cheaper but more environmentally polluting technologies. There are two crucial questions in our financial analysis. They are: (a) Why do farmers choose the waste management options that they do? and (b) What needs to be done to make farmers change their behaviour and adopt more environmentally friendly waste management options? To answer these two questions, a comparison of the different financial NPVs of the five alternative waste management methods was necessary.

3.2 Study Site and Data Collection

Intensive pig farming is carried out to various extents in all the twelve livestock regions of Thailand. This study was limited to three of the most productive and intensive pig farming areas i.e., Regions 2, 5 and 7, which are located in the central and northern parts of the country. This study analysed only the two most productive provinces in each of these three regions: Chachoengsao and Chonburi in Region 2, Chiangmai and Chiangrai in Region 5, and Nakhonpathom and Ratchaburi in Region 7. The number of pigs in these regions is approximately 55% of the total number of pigs in the country (Table 1).

Two hundred and eighty seven (287) farms were chosen for this study and the data was collected by interviewing individual farmers. Only large and medium-scale pig farms[2] were surveyed. The information collected included the number of pigs marketed each year plus the quantity of breeding stock, and the various costs and benefits of each alternative method of waste disposal.

Data on four cost categories was collected. The first cost category covered the initial costs of installing plant and equipment. The second cost category consisted of operational costs such as equipment and labour costs, electricity and other recurrent costs, and interest. The third category was mitigation costs, e.g., the purchase of chemicals to treat the waste in order to reduce odour, control the pH level and prevent infestation by noxious insects. The fourth cost category comprised the opportunity cost of land used (rent) and other private costs such as fines and compensation payments.

Data on the benefits associated with each disposal method was also collected. Each waste disposal option produces a potentially marketable product. Biogas at present can only be used to provide electricity and energy for heating and cooling equipment for domestic needs. Farmers who have installed an evaporation system[3] on their farms receive indirect benefits from using the electricity produced from the biogas to operate the system. Three kinds of data were collected to estimate the indirect benefits associated with this: the increasing number of piglets per sow per year, the reduction of the feed conversion rate (FCR) of the piggery, and the reduction of vaccine and chemical treatment. Meanwhile, there is a ready market for organic fertilizer which can also be used on the farmer's own land. Using the waste as fish feed assists in the production of catfish, which can be easily sold as well as used to feed the farmer's family and workers.

4.0 PIG FARMING AND PIG WASTE DISPOSAL IN THAILAND

4.1 Pig Farming in Thailand

The three main regions of intensive pig farming in Thailand adjoin three main rivers: the Ping, the Bang Pakong and the Tha Chin (Figure 6). As presented in Table 2, there were 287 pig farms sampled from these three regions with a total of 1,243,701 porkers and 136,663 sows. The concentration of large numbers of animals in small areas

[2] A small-scale pig farm has less than 500 heads of livestock, a medium-scale farm has between 500-5,000 ,and a large-scale farm has more than 5,000.

[3] An evaporation cooling system cools the air through the evaporation of water, and is used in climates where the air is hot and the humidity is low to provide a conducive environment for (farmed) animals. This system requires a compressor, water pumps and blowers, and runs on electricity.

and their need for large amounts of feed result in air and water pollution problems for society. Large amounts of manure have to be disposed of although some may be transported to other farms to be used as fertilizer. In many regions, however, transporting manure is not economically feasible. Waste from pig production always poses a pollution threat to rivers and streams. The Biological Oxygen Demand (BOD) levels from the Tha Chin and Bang Pakong rivers were found three times higher than the norm in 2004 (Pollution Control Department 2004).

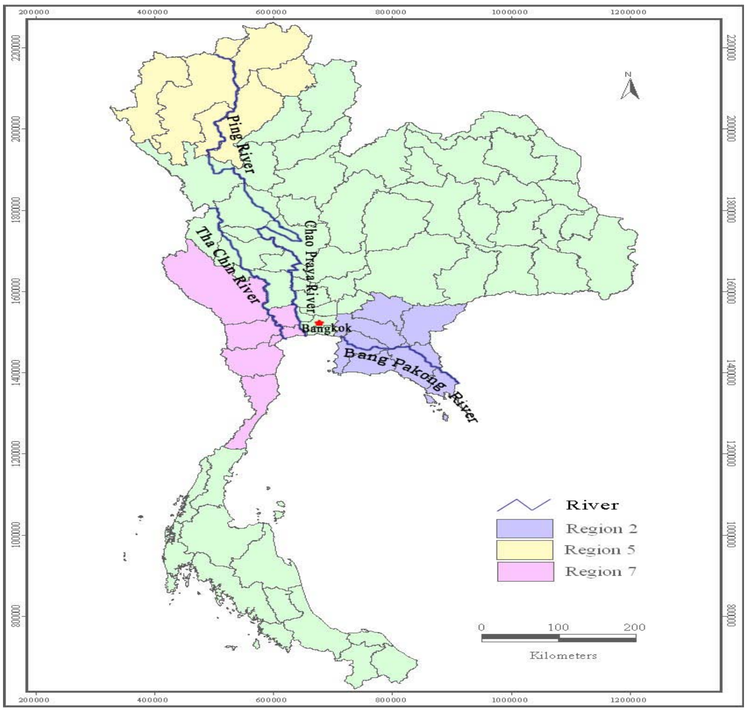

Figure 6. The three main rivers in the three main livestock regions of Thailand

4.2 Estimated Amounts of Pig Waste

The amount of waste produced by the sows and porkers per day and per year in the sampled farms in the three main regions was estimated. Manure from the sow herds averaged 4.2 kg per day, (solid waste was about 1.67kg/day and liquid waste was about 2.53 kg/day). For porkers, the daily average waste was about 3.8 kg (solid waste was about 1.51 kg/day and liquid waste was about 2.29 kg/day). The total amount of waste per pig per year was about 1,450 kg. The pig manure was disposed off by one or more of these four alternative methods: organic fertilizer, fish feed, biogas, and dumping into a deep pond. Some farmers used more than one method. The estimated amounts of pig waste by the various disposal options are presented in Table 3.

Table 2. Number of farms and pigs under each waste disposal alternative in the three main livestock regions of Thailand

Pig waste disposal alternative	Region 2			Region 5			Region 7			Total		
	Number of farms	**Number of porkers**	**Number of sows**	**Number of farms**	**Number of porkers**	**Number of sows**	**Number of farms**	**Number of porkers**	**Number of sows**	**Number of farms**	**Number of porkers**	**Number of sows**
Fertilizer	66	128,012	15,735	7	8,079	1,900	22	48,300	5,250	95 (33.10)	184,391 (14.83)	22,885 (16.74)
Fish feed	13	21,920	3,010	11	28,657	1,680	19	103,186	10,450	43 (14.98)	153,762 (12.36)	15,140 (11.08)
Biogas	23	37,676	3,232	33	103,300	14,570	31	513,457	54,450	87 (30.31)	654,433 (52.62)	72,252 (52.87)
Deep pond	0	0	0	15	7,274	0	25	28,388	3,020	40 (13.94)	35,662 (2.87)	3,020 (2.21)
Mixed	8	32,950	3,266	2	31,750	5,000	12	150,753	15,100	22 (7.67)	215,453 (17.32)	23,366 (17.10)
Total	**110**	**220,558**	**25,243**	**68**	**179,060**	**23,150**	**109**	**844,084**	**88,270**	**287 (100)**	**1,243,701 (100)**	**136,663 (100)**

Source: Survey (2005)

Note: Figures in parenthesis are the values in percentages.

Table 3. Estimated amounts of pig waste by disposal method

Pig waste disposal method	Total amount of waste per year (tonne)	Total amount of waste over 15 years (tonne)
Fertilizer	314,413	4,716,194
Fish feed	256,717	3,850,755
Biogas (concrete dome)	637,738	9,566,076
Biogas (covered lagoon)	465,720	6,985,805
Deep pond	58,859	882,879
Mixed (biogas and another method)	362,699	5,440,478

4.2.1 Organic Fertilizer

Because pig manure can be applied to agricultural land as fertilizer, this method is simple, marketable and profitable. Moreover, the initial installation cost of investment is low. Farms where this method is used are usually located outside the village. However, bad odour and floods during the rainy season pose serious problems for the neigbourhood. About 33.1% of the sampled pig farmers used this method to dispose off an estimated 314,413 tonnes of pig waste per year (Tables 2 and 3).

4.2.2. Fish feed

Intensive pig farming uses special high protein feeds designed to make pigs grow quickly, but the animals can absorb only a small amount of the nutrients they eat. The remainder is excreted in faeces and urine which can be used as fish feed. The farmers who have combined pig farming with fish ponds believe that the latter provides a relatively higher value of benefits because breeding fish is profitable and there is a ready market. However, such a combination requires a large area of land and plenty of water, and is, therefore, only found in a few areas. About 14.98% of the pig farmers in the study used this method (Table 2) and the estimated total amount of waste disposed of was 256,717 tonnes per year (Table 3).

4.2.3 Biogas

Biogas digesters and lagoons use anaerobic bacteria to digest organic material in the absence of oxygen and produce biogas (methane) as a waste product. Anaerobic processes naturally occur in swamps, water-logged fields and rice paddies, deep bodies of water and the digestive systems of termites. Methane gas is the primary output from biogas digesters and a second benefit is pollution control. Biogas can be used for heating, cooking and operating internal combustion engines, and can be converted into electricity. Before it can be used as fuel for engines, however, the hydrogen sulphide in it must be removed in order to avoid corrosion or toxicity. Biogas is an environmentally responsible technological method of disposing of animal waste and the national government has subsidized and supported the installation of many biogas systems for more than thirty years. There are two types of biogas systems installed on pig farms; the concrete dome and the covered lagoon. On a macro-economic level, biogas production also creates external economics as electricity produced from it reduces one of the main costs of pig production for farmers who have installed evaporation systems on their farms. Evaporation systems result in better sanitation and hygiene for the piggeries, and decrease deaths from disease. About 30.31% of the sampled pig farmers used the biogas method to dispose of pig waste (Table 2). The estimated total amount of waste disposed of by their biogas systems was about 1,103,458 million tonnes per year (637,738 tonnes by the concrete dome digesters and 465,720 tonnes by the covered lagoon system) (Table 3).

4.2.4 Deep pond

This method involves excavating a large pond in which to dump the slurry. Some farmers prefer this method to drying out the pig waste because it uses less land and saves installation and labour costs. A small amount of benefits can be derived from this method as the farmers can use the manure accumulated around the edges of the pond as organic fertilizer on their own fields or they can sell it. This method was used by 13.94% of the surveyed farms (Table 2) to dispose of about 58,895 tonnes of pig waste per year (Table 3).

4.2.5 Mixed (biogas and another method)

Some farmers who had invested in a fish pond to dispose of pig waste found that it could not absorb all of the manure and that the excess waste polluted the water and proved harmful to the fish and algae. These farmers, therefore, had to dispose of the rest of the manure by using another method, and they all chose biogas. About 7.67% of the pig farmers in the survey used a combination of biogas and fish pond methods to dispose of the manure and the estimated total amount of waste disposed of by this mixed method was about 362,699 tonnes per year (Tables 2 and 3).

4.3 Reasons for Choosing between Alternative Methods of Pig Waste Disposal

Table 4 shows the reasons why the farmers adopted each alternative method of pig waste disposal.

Table 4. Reasons for choosing between alternative methods of pig waste disposal

Pig Waste Disposal Method	No. of farms	Reasons	Frequency*	%
Fertilizer	95 (33.10%)	1. cash benefit 2. relatively lower initial installation cost 3. organic fertilizer profitable and marketable	21 19 11	22.11 20.00 11.58
			51	
Fish Feed	43 (14.98%)	1. relatively higher value of benefits 2. location of land is suitable 3. the fish is marketable and brings in profit	19 4 8	44.19 9.30 18.60
			31	
Biogas	87 (30.31%)	1. government subsidies 2. water pollution reduction 3. friendly to neighbourhood 4. forced by local government 5. odour reduction	21 16 7 33 8	24.14 18.39 8.05 37.93 9.20
			85	
Deep pond	40 (13.94%)	1. limited land to dry the manure 2. odour reduction 3. save installation cost 4. shortage of labour	6 3 10 10	15.00 7.50 25.00 25.00
			19	
Mixed (Biogas+other)	22 (7.67%)	1. limited amount of available land 2. government subsidies 3.relatively higher value of benefits 4. odour reduction	3 1 9 4	13.64 4.55 40.91 18.18
			17	
Total	287 (100%)			

Note: *Not all the farmers gave reasons for their choice/s.

5.0 COST AND BENEFIT ANALYSIS OF PIG WASTE DISPOSAL METHODS

5.1 Estimation of Costs

The costs associated with the alternative methods of waste disposal were classified into four categories. They are discussed below.

a) Initial costs of installation

These were the investment costs the farmers incurred in the first year to install or set up the necessary structure for the respective method of waste disposal. Among the five alternatives, the fish pond required the least investment cost, an average of 29 baht per cubic metre, while the biogas system required the highest investment. The average cost of a plastic covered lagoon was only 450 baht per cubic metre compared to a concrete dome, which cost about 1,303 baht per cubic metre. The average set-up cost for the organic fertilizer method was about 151 baht per square metre and the average cost of establishing a deep waste disposal pond was about 34 baht per cubic metre (Appendices 1-6).

b) Costs of additional equipment

In order to use the electricity made from biogas, farmers had to invest in such things like a generator and gas cleaning and processing equipment to remove the hydrogen sulphide and carbon dioxide. (The generator and gas cleaning equipment can operate for 15 years.) Meanwhile, the average installation cost of an evaporation system was 491 baht per square metre (Appendix 7). (The evaporation system can last for five years.) The total additional equipment costs for the concrete dome and covered lagoon biogas alternatives were an estimated 147,749,152 baht and 69,887,878 baht respectively (Table 5). Meanwhile the total additional equipment cost for the mixed alternative was estimated at 23,009,000 baht (Table 5). Therefore, it can be seen that the farmers invested large amounts of money for biogas equipment. This study assumed a 50% loan for total additional equipment costs in the calculations.

c) Operating and maintenance (O&M) costs

The operating and maintenance costs and the opportunity costs of land used (or rent) of each alternative method varied according to the technologies of waste disposal used by the farmers.

d) External environmental damage costs

Pollution due to pig waste such as bad odours and water pollution can affect the value of surrounding properties. People will pay less for such properties. The property value differential is an estimate of the external environmental damage costs as shown in item 4 under Undiscounted Costs in Table 5.[4] Secondary data on property values obtained from the Provincial Land Office was used for the estimates. Only the organic fertilizer and deep pond waste management options were found to create bad odours and other adverse pollution effects. The estimated external environmental damage costs from these methods were about 104,970,359 baht and 9,233,400 baht respectively (Appendix 8). The

[4] Details are given in Appendices 8, 11 and 12.

estimated property value differentials were treated as additional costs in the economic analysis.

5.2 Estimation of Benefits

The alternative methods of waste disposal produce different marketable products such as biogas, fertilizer and fish, which may be sold or used on the farm. These benefits were taken into account in the analysis.

Biogas can be used for heating, cooking and operating internal combustion engines. The sampled farmers used this renewable energy mostly on their own farms. However, less than 1% of the biogas produced was used for heating and cooling, and only about 17% was used to generate electricity for domestic use (Appendix 9). Very few farms sold the excess electricity produced from biogas to EGAT. So, around 83% of the biogas is wasted by simpy being released into the atmostphere.

The estimated total amount of biogas produced from biogas digesters in the sampled farms is about 287 million cubic metres per year and it is the primary benefit from the biogas method of waste disposal. The National Energy Policy Office (NEPO) wants biogas to be one of the main renewable energy sources used to substitute imported fuel.

Fertilizer and fish feed can be produced by traditional, simple methods of waste disposal. Conversely, farmers found that turning pig waste into biogas not only required a large investment, but also reduced their revenue derived from other methods. Naturally, most farmers, especially those relied heavily on bank credit, did not want to convert to a biogas system without financial support from the government.

The economic value of organic fertilizer was estimated at 134,880,142 baht per year for the fertilizer method. The economic value of fish was 214,614,600 baht per year for the fish feed alternative. Electricity and biogas consumed directly by the farmers were estimated at 122,774,895 baht per year in the case of the concrete dome biogas method. Similar direct benefits from the covered lagoon biogas option were valued at 134,541,000 baht per year for electricity and biogas, and 8,115,751 baht per year for organic fertilizer. The direct benefit that was brought about by the deep pond option was organic fertilizer with an economic value estimated at 69,050 baht per year. From the mixed method, there were three direct benefits produced: the economic value per year of energy and electricity was an estimated 23,656,560 baht, organic fertilizer was estimated at 3,676,070 baht, and the sale of fish was estimated at 88,900,000 baht. All these estimates are summarised in Table 5.

5.3 Results of Economic and Financial Analyses

5.3.1 Economic analysis

Table 5 shows the summary of CBA spreadsheets for the five alternative methods of pig waste disposal i.e., the fertilizer, fish feed, biogas, deep pond and mixed methods. The CBA was conducted with a time horizon of 15 years and a discount rate of 9%. The NPVs of the five alternative methods are shown in Table 5.

The NPV of the fertilizer method was 929,324,596 baht while the NPV per tonne of pig waste was 197 baht. Next, the NPV of the fish feed alternative was 1,378,484,380 baht or 358 baht per tonne of pig waste. The NPV of the concrete dome method was 1,198,008,162 baht or 125 baht per tonne of pig waste. Meanwhile, the NPV of the covered lagoon alternative was 1,005,117,721 baht or 144 baht per tonne of pig waste and the NPV of the mixed method was 739,206,640 baht or 146 baht per tonne of pig waste. Only the NPV of the deep pond method was negative—16,575,709 baht or 19 baht per tonne of pig waste—which means that the costs were greater than the benefits. Thus, the best option was the fish feed method which maximized the net benefits of waste disposal from an economic perspective.

5.3.2 Financial analysis

The figures in Table 6 show the net present values of pig waste produced by each alternative method. Both benefits and costs were estimated in terms of the financial benefits received and costs borne by the farmers. The fish feed alternative had the highest net cash benefit of 357 baht per tonne of pig waste and was the best option from a private perspective. Meanwhile, the NPVs of the concrete dome and covered lagoon biogas methods were 130 baht and 143 baht per tonne of pig waste respectively.

From a private perspective, the NPV for the concrete dome method was lower than that for fish feed, but higher than the NPVs for the fertilizer, covered lagoon and mixed methods. The concrete dome method, however, had the highest initial construction and installation cost (Appendices 1-7). Moreover in order to use the biogas, the farmers had to invest in equipment and tools. Therefore, the NPV per tonne of pig waste for the concrete dome method was relatively lower than for the other alternative methods, except the deep pond option. This was due to the lack of access to a market to sell the surplus as electricity; less than 20% of the biogas was consumed with the remaining simply released into the atmosphere. Pig waste could be a resource rather than a nuisance if the farmers, especially from the large farms, managed to produce electricity efficiently from the biogas. However, only one farm in the survey was found to be selling electricity produced from biogas to EGAT.

Table 5. Costs, benefits and NPVs estimated from an economic perspective for the five pig waste disposal methods

(Unit: baht)

Description	Fertilizer	Fish feed	Biogas		Deep pond	Mixed
			Concrete dome	Covered lagoon		
Costs (undiscounted)						
1. Capital costs (installation costs)	17,640,900	72,870,000	83,751,000	110,104,500	1,676,055	41,051,570
2. Additional equipment costs	0	0	147,749,152	69,887,878	0	23,009,000
3. Operating and maintenance costs (O8M costs)	6,254,964	37,872,216	10,090,607	3,400,942	942,736	10,503,091
4. Additional costs (Value of external damage costs)	104,970,359	0	0	0	9,233,400	0
Benefits (undiscounted)						
1. Energy (Biogas + Electricity)	0	0	122,774,895	134,541,000	0	23,565,560
2. Organic fertilizer	134,880,142	0	57,659,613	8,115,751	69,050	3,676,070
3. Fish	0	214,614,600	0	0	0	88,900,000
4. Subsidies paid to farmers	0	0	0	0	0	0

Table 5 (Continued)

Description	Fertilizer	Fish feed	Biogas		Deep pond	Mixed
			Concrete dome	Covered lagoon		
Costs (Discounted PV)						
1. Capital costs	11,179,811	46,180,910	76,835,780	69,778,043	1,062,189	37,661,991
2. Additional equipment costs	0	0	98,254,170	47,541,924	0	21,384,241
3. O&M costs	50,419,312	305,276,133	81,337,239	27,413,934	(58,357,450)	84,662,144
4. Additional costs (Value of external damage costs)	96,303,081	0	0	0	74,427,561	0
TOTAL COSTS	**157,90,204**	**351,457,043**	**256,427,189**	**144,733,901**	**16,070,111**	**143,708,376**
Benefits (Discounted PV)						
Benefits	1,087,226,800	1,729,941,423	1,454,426,351	1,149,911,622	556,591	936,915,016
Subsidies paid to farmers	0	0	0	0	0	0
TOTAL BENEFITS	**1,087,226,800**	**1,729,941,423**	**1,454,426,351**	**1,149,911,622**	**556,591**	**936,915,016**
NPV	**929,324,596**	**1,378,484,380**	**1,198,008,162**	**1,005,177,721**	**(16,575,709)**	**793,206,640**
NPV per tonne of pig waste	**197**	**358**	**125**	**144**	**(19)**	**146**

Note: Discount rate = 9%; T = 15 years

Table 6. Costs, benefits and NPVs estimated from a private perspective for the five pig waste disposal methods

(Unit: baht)

Description	Fertilizer	Fish feed	Biogas		Deep pond	Mixed
			Concrete dome	Covered lagoon		
Cost (Undiscounted)						
1. Capital costs (Installation costs)	17,640,900	72,870,000	83,751,000	110,104,500	1,676,055	41,051,570
2. Additional equipment costs	0	0	147,749,152	69,887,878	0	23,009,000
3. Operating and Maintenance Costs (O&M costs)	6,254,964	37,872,216	10,090,607	3,400,942	942,736	10,503,091
4. Equal annual repayment of loans	1,511,781	6,244,776	15,265,796	12,650,088	143,634	5,823,745
- Payment of installation loan	1,511,781	6,244,776	8,623,234	9,435,679	143,634	4,634,993
- Payment of additional equipment loan (gas cleaning equipment & generator)	0	0	1,008,009	710,826	0	655,992
- Payment of additional equipment loan (evaporation system, equipment and tools	0	0	5,634,552	2,503,583	0	532,760
Benefits (Undiscounted)						
1. Energy (Biogas + Electricity)	0	0	122,774,895	134,541,000	0	23,656,560
2. Organic fertilizer	134,880,142	0	57,659,613	8,115,751	69,050	3,676,070
3. Fish	0	214,614,600	0	0	0	88,900,000
4. Subsidies paid to farmers	0	0	48,996,397	0	0	12,695,953

Table 6 (Continued)

Description	Fertilizer	Fish feed	Biogas		Deep pond	Mixed
			Concrete dome	Covered lagoon		
Cash costs (Discounted PV)						
1. Capital cash costs	12,185,994	50,337,192	69,509,206	76,058,067	1,157,786	37,361,235
2. Additional equipment cash costs	0	0	103,842,328	50,203,895	0	18,484,340
3. O&M cash costs	50,419,312	305,276,133	81,337,239	27,413,934	7,599,101	84,662,144
TOTAL CASH COSTS	**62,605,306**	**355,613,325**	**254,688,773**	**153,675,896**	**8,756,888**	**140,507,719**
Benefits (Discounted PV)						
Direct benefits	1,087,226,800	1,729,941,423	1,454,426,351	1,149,911,622	556,591	936,915,016
Subsidies paid to farmers	0	0	48,996,397	0	0	12,695,953
TOTAL BENEFITS	**1,087,226,800**	**1,729,941,423**	**1,503,422,748**	**1,149,911,622**	**556,591**	**949,610,969**
NPV	**1,024,621,494**	**1,374,328,098**	**1,244,688,401**	**996,235,726**	**(8,200,297)**	**808,054,960**
NPV per tonne	**217**	**357**	**130**	**143**	**(9)**	**149**

Note: Discount rate = 9%, T = 15 years

5.4 Sensitivity Analysis

How to induce farmers who are currently using cheaper but more environmentally polluting technologies to switch to biogas production is the crucial question for policy-makers. A sensitivity analysis is a sensible and suitable approach to gauge how the NPVs will change if some of the costs and benefits deviate from their assumed values. Such an analysis was conducted to determine the impact of variations in the input components on the NPVs of each alternative. The results showed that selling surplus electricity to EGAT was the best option with the second best being the installation of an evaporation system on the farm.

5.4.1 The "best case" scenario

Three scenarios were simulated to find "the best case". They were a) the installation of an evaporation system on the farm; b) converting biogas into electricity and selling the surplus to EGAT; and c) an increase of 20% in benefits for all alternative methods. The results of the simulations are shown in Table 7.

a) Scenario 1: The installation of an evaporation system on the farm.

Evaporation systems have been proven to increase the level of hygiene and sanitation on pig farms, resulting in the following benefits.

i) A reduction in the mortality rates of newborn piglets.

ii) An overall increase in the number of litters produced per annum.

iii) A reduction in the average feed conversion rate (FCR).[5]

Improving hygiene, therefore, results in an increase in the productivity, efficiency and profitability of the farm. .

b) Scenario 2: Converting biogas into electricity and selling the surplus to EGAT.

Biogas can also run generators to produce electricity. The surplus electricity can be sold to EGAT. Large-scale pig farms seem to benefit more from this in terms of comparative advantage (the average cost of electricity production in large-scale pig farms is relatively lower than in smaller farms). The estimated quantity of biogas produced from biogas digesters under the biogas and mixed alternative methods was about 302,067,320 cubic metres per year (Appendix 15).

Only 17% of the total biogas produced or 50,595,825 m^3 per year was consumed for household uses on the sampled local farms (Appendices 9 and 16). On the other hand, 83% of the total biogas produced (or 251 million cubic

[5] FCR is a measure of an animal's efficiency in converting feed mass into increased body mass. It is calculated in terms of the amount of feed consumed in relation to body weight, for e.g., a 100 kg pig with an FCR of 5 would mean that the pig consumes 500 kg of feed for its body weight of 100 kg.

metres per year) was simply released into the atmosphere. This could be used as fuel in the same way as petrol and diesel. Appendices 10 and 15 show that biogas has competitive value compared to other energy resources.

In 2005, the Thai government imposed a requirement on EGAT to buy electricity (produced from surplus biogas) from all farmers, including pig farmers.

c) Scenario 3: An increase of 20% in benefits for each alternative method.

5.4.2 The "worst case" scenario

Five scenarios, as listed below, were simulated to find the "worst case".

a) Scenario 1: No subsidy from the government for the concrete dome biogas system.

Currently, there is no government subsidy for the covered lagoon system, only for the concrete dome system.

b) Scenario 2: A 20% increase in operating and maintenance costs, and a market interest rate increase of 3%.

c) Scenario 3: A 20% decrease in benefits derived from each method.

Risk factors, for example, sickness in pigs or the fish in the ponds and fluctuations in the prices of the secondary products sold like fertilizer and fish can reduce the value of benefits. This is a probable scenario change based on actual occurrences in the past.

d) Scenario 4: The present concessional interest rate of 6% for loans to install a concrete dome biogas system is discontinued and the market interest rate of 9% for other loans is increased by approximately 3%.

e) Scenario 5: A 20% increase in operating and maintenance costs and rent.

For all the waste disposal methods, the core investment is the initial installation cost and the opportunity cost of land (rent), which represents about 62% of the total investment. The operating and maintenance costs make up the remaining 38%.

5.4.3 "Best case" versus "worst case"

From a private financial perspective, the results in Table 7 clearly show that the "best case" is if the farmers sell the surplus electricity to EGAT as this provides the highest NPVs of 760 baht per tonne of pig waste for the concrete dome method and 681 baht per tonne of pig waste for the covered lagoon method.

In the next best scenario i.e., the conversion to biogas with the adoption of an evaporation system on the farm, the NPV of the concrete dome method is 198 baht per tonne of pig waste while the NPV of the covered lagoon option is slightly lower at 191 baht per tonne. However, the evaporation system increased the NPVs of the covered lagoon and mixed methods.

For the “worst case” scenario, Table 7 shows that the NPVs per tonne of pig waste under the biogas methods are lower than for the other methods except for the deep pond option. The NPVs per tonne of pig waste for all methods of pig waste disposal decrease slightly compared to the base case. A subsidy appears only slightly significant to the cost-benefit analyses of the concrete dome and mixed methods. Without the subsidy, the NPV per tonne of pig waste for the concrete dome alternative decreases by 5 baht. Similarly, in the scenario where the interest rate for loans increases by 3%, the NPV per tonne of pig waste decreases 2 baht for the concrete dome alternative and 2 baht for the mixed alternative. Therefore, capital subsidy grants and concessional interest rates on loans by farmers who choose to invest in biogas digesters have only slight effects on their financial situation. Finally, Scenarios 3 and 5 generally showed a decrease in NPVs for all options.

Table 7. Summary of the sensitivity analysis (best case–worst case) of the five pig waste disposal methods

(Unit: baht per tonne)

CASE	COST-BENEFIT ANALYSIS											
	Fertilizer		Fish feed		Biogas				Deep pond		Mixed	
					Concrete dome		Covered lagoon					
	Social	Private	Social	Private	Social	Private	Social	Private	Social	Private	Social	Private
Base case	**197**	**217**	**358**	**357**	**125**	**130**	**144**	**143**	**(19)**	**(9)**	**146**	**149**
BEST CASE SCENARIOS												
SALE OF ELECTRICITY TO EGAT	197	217	358	357	755	760	682	681	(19)	(9)	583	586
INDIRECT BENEFITS FR EVAPORATION SYSTEM	197	217	358	357	193	198	192	191	(19)	(9)	210	213
BENEFITS UP BY 20%	243	263	448	447	156	161	177	176	(19)	(9)	180	183
WORST CASE SCENARIOS												
NO SUBSIDY	197	217	358	357	125	125	144	143	(19)	(9)	146	146
COST UP BY 20% AND INTEREST UP BY 3%	195	215	345	343	124	127	143	141	(19)	(10)	144	145
BENEFITS DOWN BY 20%	151	171	268	267	95	100	111	110	(19)	(9)	111	114
INTEREST UP BY 3%	197	217	358	356	125	128	144	141	(19)	(9)	146	147
O & M COSTS AND RENT UP BY 20%	195	215	342	341	124	128	143	142	(20)	(11)	143	145

Note: Figures are in net present values

5.5 Technical and Institutional Barriers to Each Method

Pig farmers dispose of pig waste by means of five different methods: fertilizer, fish feed, biogas, deep pond and mixed. The technical and institutional barriers of the first four are described below. The mixed method is simply a combination of two or more of the different alternatives and the relevant barriers of the selected methods would apply to it.

a) **Organic fertilizer:** This alternative fails to address the problem of water and air pollution. It creates a bad odour in the surrounding area. During the rainy season, this technique fails to work effectively and excess waste overflows the pits. The local government has tried to enforce all the protective regulations such as the Ministerial Notification on Livestock Farm Standards of Thailand (1999), but have not been very successful especially with the older farms (established before 2000).

b) **Fish feed:** This alternative requires a large suitable piece of land and can be applied to only catfish, which can live in ponds with low water quality. This alternative also requires considerable investment and labour costs, and is inadequate in disposing of the huge volume of waste produced by large farms.

c) **Biogas:** This method has had limited success. Barriers which prevent the successful installation and operation of the biogas system are as follows:

   i) High investment cost to farmers, in spite of the fact that NEPO is willing to subsidize up to 38% of the concrete dome biogas system installation cost and negotiate with Thai banks to provide a low interest loan.

   ii) Incorrect operation of the system and failure to maintain or repair it.

   iii) High incremental cost in using biogas as renewable energy for running generators, gas cleaning equipment, and evaporation systems on the farm.

   iv) Complicated processing in selling surplus electricity to EGAT.

d) **Deep pond:** This method causes more serious environmental problems, like bad odours and insect infestation, compared to the others. Therefore, the local government has had to enforce protective environmental regulations to address these threats. In this method, the farmers dump the waste into a pond and leave it for years. Only the dry manure around the edge of the pond can be used or sold as fertilizer unlike in the organic fertilizer method where the farmers invest in labour and building a platform to dry all the solid waste. So, the farmers who use the deep pond method gain a very small amount of benefit compared to those who invest fully in converting solid pig waste to fertilizer and earn much bigger cash returns.

Table 8. Cost-benefit analysis of the five pig waste disposal methods

(Unit: baht per tonne)

Pig waste disposal method	ECONOMIC ANALYSIS NPV per tonne of waste	ECONOMIC ANALYSIS Place in ranking*	FINANCIAL ANALYSIS NPV per tonne of waste	FINANCIAL ANALYSIS Place in ranking*
Fertilizer	197	2	217	2
Fish feed	358	1	357	1
Biogas – Concrete dome	125	5	130	5
Biogas – Covered lagoon	144	4	143	4
Deep pond	(19)	6	(9)	6
Mixed	146	3	149	3

Note: * 1 = best option (most benefit-effective); 6 = worst option (least benefit-effective)

Table 9. Net Present Values under the five pig waste disposal methods

(Unit: baht)

Pig waste disposal method	ECONOMIC ANALYSIS NPV	PRIVATE ANALYSIS NPV
Fertilizer	929,324,596	1,024,621,494
Fish feed	1,378,484,380	1,374,328,098
Biogas-Concrete dome	1,198,008,162	1,244,688,401
Biogas-Covered lagoon	1,005,177,721	996,235,726
Deep pond	(16,575,709)	(8,200,297)
Mixed	793,206,640	808,054,960

There are several inferences we can make from Tables 8 and 9.

a) The fish feed and fertilizer methods provide the largest and second largest financial and social net benefits to the farmers. These methods require a relatively lower initial cost of investment, lower management cost and simpler technology compared to the other methods.

b) The biogas concrete dome and covered lagoon alternatives rank fourth and fifth. These methods have large social but low financial net benefits for the farmers. The latter is the reason why many farmers are reluctant to adopt the biogas option to dispose of waste on their farms in spite of the fact that the technology would provide energy for the farm as well as avoid the serious environmental problems that would arise from other methods of waste disposal. Furthermore, the farmers would be able to derive significant economic benefits from a combination of domestic use and sale of the gas and electricity. Ironically, at the moment, much of the surplus biogas is simply released into the atmosphere.

c) The deep pond alternative is the least beneficial option, ranking at sixth place with negative returns.

d) The present values of net returns from the production of benefits under each option were derived from the results in Tables 5 and 6. In terms of the net present values, the concrete dome biogas option has the second highest values with 1,198,008,162 baht for economic analysis and 1,244,688,401 baht for financial analysis. But in terms of NPV per tonne of pig waste, it ranks fifth for both the economic and financial analyses.

6.0 CONCLUSIONS

Pollution from medium and large-scale farms, particularly those devoted to pig production, continues to be a major cause of public concern in Thailand. The national government has enacted and is attempting to enforce restrictive regulations in an attempt to persuade farmers to dispose of animal waste in a manner which causes the least damage to the environment while remaining economically feasible for the farmers themselves.

One possible solution for intensive pig farms is the conversion of solid and liquid pig waste to biogas, a technology which is proven, readily available and economically feasible. For more than 30 years, the government has subsidized and supported the installation of many biogas systems, but with very limited success.

This study carried out a CBA of five alternative methods of pig waste disposal used on pig farms in the three main livestock regions of Thailand. The results of the study showed that among the five alternatives, the fish feed alternative produced the highest NPV per tonne of pig waste (357 baht) from a private perspective. The second best was the organic fertilizer option of which the NPV per tonne of pig waste was 217 baht while the biogas alternative produced the least benefits from the waste, especially the concrete dome method which had the highest initial construction and installation cost. To produce biogas, farmers had to invest large amounts of capital on the necessary equipment and tools. However, most of the biogas was unused and routinely released into the atmosphere.

A sensitivity analysis was carried out to find the “best case” and “worst case” scenarios. The results showed that the sale of surplus electricity produced from biogas to EGAT provided the highest NPVs i.e., 760 and 681 baht per tonne of pig waste from the concrete dome and covered lagoon biogas methods respectively (Table 7). The next best alternative was combining biogas production with the installation of an evaporation system resulting in a significant increase in the productivity, efficiency and profitability of the farm.

To assist pig farmers in choosing the most appropriate pollution control technology, the government should implement policies to promote the production and utilisation of renewable energy as well as provide technical and financial support to encourage pig farmers who are using other methods of waste disposal to switch to biogas production.

Medium and large-scale pig farms produce large amounts of biogas from their pig waste (302 million cubic metres per year equivalent to 363 megawatts per year – see Appendix 10), and this potentially valuable source of renewable energy should not be wasted. At present, a resource which has the potential to increase the profitability and productivity of pig farms, and at the same time, contribute positively to the economy of Thailand, is simply being wasted.

7.0 POLICY RECOMMENDATIONS

Based on the results of this study and the outcome of the focus group discussions, several policy recommendations are proposed to help induce farmers to switch from poor technology waste management options to clean, biogas technology.

a) A basic principle in environmental economics is that taxes can provide an incentive for polluters to adopt socially efficient rates of pollution. In effect, these taxes have changed the pattern of private net benefits so that they are the same as social net benefits. A charge based on the social costs of disposal is not going to be feasible as it would require the authorities to evaluate the waste produced by each alternative and charge according to the different items identified. In the case of pig waste disposal in Thailand, a single charge per tonne should be established for all disposal methods, except for biogas production as it is an environmentally "clean" method.

b) In principle, it would be possible to apply a pollution charge as a means of "internalizing" the externalities, assuming that some waste management technologies (like the fertilizer and deep pond methods) do have adverse environmental effects such as bad odours and water pollution. Instead of applying the charge explicitly to odours or water pollution damage (which would be difficult in practice), we could consider a charge on the volume of waste handled by the more polluting technologies. This could be calculated in terms of the number of animals on the farm with a charge levied per animal. In this way, a farmer converting all his pig waste to fertilizer with adverse environmental effects, for example, might be subject to the charge whereas a biogas producer would be exempt.

c) Inducing farmers to switch from low-cost technologies to costly biogas technology remains a big challenge for policy-makers. The major obstacle to the success of the biogas system is the lack of access to a market. One of suggestions from the focus groups was to establish a centralized facility that would collect either the biogas or pig waste. However, it would be costly if the farms are located far from one another.

d) If the funds raised from the charge/tax (from (a) above) were "earmarked", they could be used to subsidize the installation of biogas facilities on farms which have not yet converted to biogas. This would be sufficient to induce farmers to switch to biogas production rather than continuing to use cheaper, but more environmentally polluting technologies such as fertilizer and deep pond.

e) The government should implement policies to promote the production of renewable energy as well as provide the necessary technical and financial support to encourage farmers to install biogas systems, especially those from medium and large-scale pig farms, which can produce large amounts of biogas from their waste. At present, more than 80% of the biogas produced on such farms is being simply wasted as consumption levels are only around 17%. The surplus gas has potential economic value, but that potential is not being realized. The large-scale pig farmers in the study managed to produce electricity from the biogas efficiently and could sell the surplus to the EGAT at a profit, but except for one, none of the others did so. Meanwhile, the medium-scale pig farmers mostly compressed the biogas in high compressor cylinder tanks and used these to run farm vehicles and machines.

There is a pressing need to create conditions that would allow the biogas option to be fully exercised, bringing benefit to both the farmers and the economy of Thailand.

REFERENCES

Atkinson, D. and C. A. Watson. 1996. The environmental impact of intensive systems of animal production in the lowlands. Animal Science. 63, 353 – 361.

Berentsen, P. B. M. and G. W. J. Giesen. 1996. Economic aspects of dairy cows to contain environmental pollution. C. J. C. Phillips (ed.). *In* Progress in Dairy Science. CAB International. Wallingford, UK. 343-374.

Catelo, A. O.; M. A. Dorado; and E. Agbisit Jr. 2001. Backyard and commercial piggeries in the Phillipines: Environmental consequences and pollution control options. Research report. Economy and Environment Program for Southeast Asia (EEPSEA). Singapore.

Compassion in World Farming Trust (CWFT). 1996. Factory Farming and the Environment. Surrey, UK.

Delgado, C.; M. Rosegrant; H. Steinfeld; S. Ehui; and C. Courbois. 1999. Livestock to 2020: The next Food Revolution. 2020 Vision discussion paper No. 28. International Food Policy Research Institute. Washington, D.C.

Food and Agriculture Organization of the United Nations (FAO). 1995. Production Yearbook 1994. Rome, Italy.

Hann, C. H.; H. Steinfeld; and H. Blackburn. 1996. Finding a balance: A study coordinated by the Food and Agriculture Organization, the US Agency for International Development and the World Bank. European Commission for Livestock and the Environment. WRENmedia, UK.

Intarangsi, K. 2002. The experience on biogas technology in Thailand: From development to delivery. Biogas Advisory Unit, Institute for Science and Technology Research and Development, Chiang Mai University. Chiang Mai, Thailand.

Ministry of Agriculture, Fisheries and Food. 1990. Codes of recommendation for the welfare of livestock. Her Majesty's Stationery Office. London, UK.

National Energy Policy Office (NEPO). 2004. Promotion of energy efficiency and renewable energy in Thailand. Energy Conservation and Renewable Energy Division, National Energy Policy Office. Bangkok, Thailand.

Nguyen, Q. C. 2004. Dairy cattle development, environmental consequences and pollution control option in Hanoi Province, North Vietnam. Progress report to the Economy and Environment Program for Southeast Asia (EEPSEA). Singapore.

Pain B. F.; Misselbrook T. H.; and Crarkson, C. R. 1990. Odour and ammonia emmissions following the spreading of anaerobically-digested pig slurry on grassland. Biological Waste. 34, 259-276.

Pain, B.F. 1994 (a). Odours from landspreading livestock waste (English), Institute of Grassland and Environmental Research, Okehampton (United Kingdom). J.E. Hall (ed), *In* Animal Waste Management. Proceedings; European System of Cooperative Research Networks in Agriculture (ESCORENA); REUR Technical Series (FAO), No. 34; European Cooperative Research Network on Animal Waste Management. Technical Consultation, 7, Bad Zwischenahn (Germany), 17-20 May 1994. FAO, Rome (Italy). Regional Office for Europe. 1994. 151-155.

Pain, B. F. 1994 (b). Odour nuisance from livestock production systems. A. Deni (ed), *In* Pollution in livestock production systems. CAB International. Wallingford, UK. 241-263.

Pollution Control Department. 2004. Annual report - Water Quality Management Bureau. Ministry of Natural Resources and Environment. Bangkok, Thailand.

Richert, B. T.; M. D. Tokach; R. D. Goodband; and J. L. Nelssen. 1994. Assessing producer knowledge and awareness of environmental issues impacting the swine industry. J. Animal Science. 72 (Suppl. 2), 43 (Abstr.).

Silverman, S. 1999 (1st August). Chicken's big impact on region. Washington Post. USA.

United States Environmental Protection Agency (USEPA). 1995. Global impact domain–methane emission. Consultant report for the livestock and the environment study. USEPA, Washington, D.C., USA.

Wathes, C. M.; Holden M. R.; Sneath R.W.; White R.P.; Phillips V.R.; et al. 1997. Concentrations and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in UK broiler and layer houses. British Poultry Science. 38(1).

World Society for the Protection of Animals (WSPA). 1999. Intensive farming and environmental health pollution by manure, slurry and animal carcasses. London, UK.

APPENDICES

Appendix 1. Average cost of biogas installation (concrete dome)

Region	Type of biogas system				
	Concrete dome				
	Farms	Capacity (m^3)	(baht)	Average cost	
				(baht/farm)	(baht/m^3)
2	22	3,030	3,920,000	178,181	1,294
5	25	15,450	20,481,000	819,240	1,326
7	16	45,800	59,350,000	3,709,375	1,296
Total	**63**	**64,280**	**83,751,000**		
Average Cost				**1,329,381**	**1,303**

Appendix 2. Average cost of biogas installation (covered lagoon)

Region	Type of biogas system				
	Covered lagoon				
	Farms	Capacity (m^3)	(baht)	Average cost	
				(baht/farm)	(baht/m^3)
2	1	10,395	3,500,000	3,500,000	337
5	8	14,430	8,721,500	1,090,188	604
7	15	56,650	24,480,000	1,632,000	432
Total	**24**	**81,475**	**36,701,500**		
Average Cost				**1,529,229**	**451**

Appendix 3. Average cost of fertilizer installation

Region	Farms	Capacity (m^3)	(baht)	Average cost	
				(baht/farm)	(baht/m^3)
2	66	15,620	2,656,740	40,254	170
5	7	8,640	1,084,560	154,937	126
7	22	14,900	2,139,000	97,227	144
Total	**95**	**39,160**	**5,880,300**		
Average Cost				**61,898**	**150**

Appendix 4. Average cost of fish pond installation

Region	Farms	Capacity (m^3)	(baht)	Average cost	
				(baht/farm)	(baht/m^3)
2	13	221,130	5,888,000	452,923	27
5	11	272,348	7,702,000	700,182	28
7	19	355,890	10,700,000	563,158	30
Total	**43**	**849,368**	**24,290,000**		
Average Cost				**564,884**	**29**

Appendix 5. Average cost of deep pond installation

Region	Farms	Capacity (m^3)	(baht)	Average cost (baht/farm)	Average cost (baht/m^3)
2	0	0	0	0	0
5	15	13,640	474,685	31,646	34
7	25	2,780	84,000	3,360	30
Total	**40**	**16,420**	**558,685**		
Average Cost				**13,967**	**34**

Appendix 6. Average cost of mixed method installation

Region	Farms	Capacity (m^3)	(baht)	Average cost (baht/farm)	Average cost (baht/m^3)
2	8	9,065	10,465,570	1,308,196	1,154
5	4	4,348	12,736,000	3,184,000	2,929
7	12	47,000	17,850,000	1,487,500	379
Total	**24**	**60,413**	**41,051,570**		
Average Cost				**1,710,482**	**680**

Appendix 7. Average installation cost of an evaporation system

Region	Pigs (no.)	Area (m^3)	Fan (baht)	Cooling pad (baht)	Control System (baht)	Plastic and wire (baht)	Pump(s) (baht)	Labour and other costs (baht)	Total cost of evaporation system installation (baht)	Average cost (baht/m^3)	Depreciation* (baht/year)
2	5,912	12,180	1,905,644	567,388	226,483	825,720	136,244	2,236,521	5,898,000	484	570,337
5	14,220	27,080	733,144	1,425,639	542,963	2,036,834	815,896	8,963,234	14,517,710	536	710,352
7	35,350	82,875	2,080,975	3,868,630	1,395,244	5,684,032	2,168,176	24,440,542	39,637,599	478	1,944,621
Total	**55,482**	**122,135**	**4,719,763**	**5,861,657**	**2,164,690**	**8,546,586**	**3,120,316**	**35,640,297**	**60,053,310**	**491**	**3,225,309**

Notes: *Depreciation of fan and pump = 20%. Depreciation of cooling pad, control system and equipment = 10%

Appendix 8. An assessment of external environmental damage costs (Unit: baht)

Waste disposal method	Value of land without pollution	Value of house without pollution	% difference in value	Estimate of the value of property affected*
Organic fertilizer	1,050,645,000	165,412,875	8%	104,970,359
Deep pond	282,600,000	24,879,000	3%	9,233,400
Total	**1,333,245,000**	**190,291,875**	**6%**	**114,203,759**

Note: * = figures taken from spreadsheet calculations

Appendix 9. Total amount of biogas produced from biogas digesters

Waste disposal method		Household consumption of biogas	%	Biogas converted to electricity	%	Loss	%	Total
Biogas	**(m^3)**	435,064	0.18	42,305,608	17.27	202,289,958	82.56	**245,030,630**
	(baht)	3,482,250		253,833,645		-		**-**
Mixed	**(m^3)**	90,915	0.16	7,764,240	13.61	49,181,536	86.23	**57,036,690**
	(baht)	727,680		46,585,440		-		**-**
Total	**(m^3)**	525,978	0.17	50,069,848	16.58	251,471,494	83.25	**302,067,320**
	(baht)	4,209,930		300,419,085		-		**-**

Appendix 10. The equivalent of biogas values compared to values of other energy resources

Energy resource	Quantity	Value (baht)
LPG (Liquefied Petroleum Gas) (kg)	138,950,967	2,417,746,828
Diesel (litre)	181,240,392	3,296,762,729
Electricity (kw)	362,480,784	1,812,403,919

Notes: 1 m^3 of biogas is equivalent to LPG 0.46 kg of LPG (17.40 baht/kg); 0.60 litres of diesel (18.19 baht/litre); and 1.2 kw/hr of electricity (5 baht/kw).

Appendix 11. An estimate of the value of properties affected in the case of the deep pond method

Region	Total surrounding area (rai)	Value of land without pollution (baht)	Housing value without pollution (baht)	Total property value without pollution (baht)	% difference in value	Estimated value of property affected*
2	292	103,560,000	12,735,000	116,295,000	2%	2,321,900
5	441	179,040,000	12,144,000	191,184,000	4%	6,911,500
7	-	-	-	-	-	-
Total	**733**	**282,600,000**	**24,879,000**	**307,479,000**		**9,233,400**

Note: * = figures taken from spreadsheet calculations

Appendix 12. An estimate of the value of properties affected in the case of the organic fertilizer method

Region	Total surrounding area (rai)	Value of land without pollution (baht)	Housing value without pollution (baht)	Total property value without pollution (baht)	% difference in value	Estimated value of property affected*
2	1,395	359,990,000	58,572,800	418,562,800	8%	30,634,488
5	221	96,100,000	9,260,000	105,360,000	8%	12,210,000
7	292	129,990,000	16,604,600	146,594,600	8%	13,843,740
Total	**1,908**	**586,080,000**	**84,437,400**	**670,517,400**		**56,688,228**

Note: * = figures taken from spreadsheet calculations

Appendix 13. Indirect benefits from an evaporation system with the biogas and mixed methods (sows)

Region	No. of sows per year	Reduction of mortality rate in piglets	Reduction in treatment and labour costs (baht)	Total benefit (baht)	Average benefit (baht/sow/year)
2	3,312	1,959,703	31,865	1,991,568	601
5	5,750	4,079,340	55,055	4,134,395	719
7	29,850	17,548,200	277,900	17,826,100	597
Total	**38,912**	**23,587,243**	**364,820**	**23,952,063**	**616**

Appendix 14. Indirect benefits from an evaporation system with the biogas and mixed methods (porkers)

Region	Stock	Number of porkers per year*	FCR** reduction	Reduction in treatment and labour costs	Total Benefit	Average benefit (baht/porker/year)
2	2,600	6,240	936,000	9,360	945,360	152
5	8,470	20,328	3,634,800	29,427	3,664,227	180
7	5,500	13,200	2,304,000	14,100	2,318,100	176
Total	**16,570**	**39,768**	**6,874,800**	**52,887**	**6,927,687**	**174**

Notes: *The number of piglets produced each year could increase to an average of 2.4 per piggery. **FCR = Feed Conversion Rate

Appendix 15. Estimated quantities of biogas produced from biogas digesters (biogas and mixed methods)

Method	Region 2			Region 5			Region 7			Total		
	Total amount of waste (tonne)	Solid waste (tonne)	Gas (m^3)	Total amount of waste (tonne)	Solid waste (tonne)	Gas (m^3)	Total amount of waste (tonne)	Solid waste (tonne)	Gas (m^3)	Total amount of waste (tonne)	Solid waste (tonne)	Gas (m^3)
Biogas	62,240	24,747	13,882,910	178,567	69,040	38,731,545	862,652	342,988	192,416,174	1,103,459	436,775	245,030,630
Mixed	55,042	21,885	8,271,594	55,608	22,109	10,839,368	252,048	100,214	37,925,728	362,698	144,208	57,036,690
Total	**117,282**	**46,631**	**22,154,505**	**234,175**	**91,149**	**49,570,913**	**1,114,700**	**443,202**	**230,341,901**	**1,466,157**	**580,982**	**302,067,320**

Appendix 16. Value of biogas and electricity produced from the biogas methods

Energy produced	Volume of biogas (m^3)	LPG and electricity quantities*	Value (baht)**
1. Biogas for household consumption	525,978	241,950 (kg of LPG)	4,209,930
2. Electricity	50,069,847	60,083,817 (kw)	300,419,085
Total	50,595,825	-	304,629,015

Notes: * 1 m^3 biogas = 1.2 kw or 0.46 kg of LPG.
** Household consumption cost is 5 baht/kw for electricity and 17.40 baht/kg for LPG produced from biogas digesters.